

## Recent Charmonium Physics from BES

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(Received May 16, 2003 )

Measurements of branching fractions for  $\psi(2S)$  decays into  $\omega\pi^+\pi^-$ ,  $b_1\pi$ ,  $\omega f_2(1270)$ ,  $\omega K^+K^-$ ,  $\omega pp\bar{p}$ ,  $\phi\pi^+\pi^-$ ,  $\phi f_0(980)$ ,  $\phi K^+K^-$ , and  $\phi pp\bar{p}$  final states, based on a data sample of  $(4.02 \pm 0.22) \times 10^6$   $\psi(2S)$  events collected with the BESI detector at the Beijing Electron-Positron Collider, are reported. Using the same event sample, radiative decays of the radially excited charmonium resonance,  $\psi(2S)$ , into  $\pi\pi$ ,  $K\bar{K}$  and  $\eta\eta$  final states have been measured. The branching ratios  $B(\psi(2S) \rightarrow \gamma f_2(1270)) = (2.12 \pm 0.19 \pm 0.32) \times 10^{-4}$  and  $B(\psi(2S) \rightarrow \gamma f_0(1710)) \times B(f_0(1710) \rightarrow K^+K^-) = (3.02 \pm 0.45 \pm 0.66) \times 10^{-5}$  are obtained.

Cross sections for  $e^+e^- \rightarrow e^+e^-$ , hadrons,  $\pi^+\pi^-J/\psi$ , and  $\mu^+\mu^-$  have been measured in the vicinity of the  $\psi(2S)$  resonance using the BESII detector. The  $\psi(2S)$  total width; partial widths to hadrons,  $\pi^+\pi^-J/\psi$ , and muons; and corresponding branching fractions have been determined to be  $\Gamma_t = 264 \pm 27$  keV,  $\Gamma_h = 258 \pm 26$  keV,  $\Gamma_\mu = 2.44 \pm 0.21$  keV, and  $\Gamma_{\pi^+\pi^-J/\psi} = 85.4 \pm 8.7$  keV; and  $B_h = (97.79 \pm 0.15)\%$ ,  $B_{\pi^+\pi^-J/\psi} = (32.3 \pm 1.4)\%$ ,  $B_\mu = (0.93 \pm 0.08)\%$ , respectively.

Decays of  $J/\psi \rightarrow \gamma\eta_c$  are used to determine the mass and width of the  $\eta_c$  using a sample of 58 M  $J/\psi$  events:  $M_{\eta_c} = (2977.5 \pm 1.0 \pm 1.2)$  MeV and  $\Gamma_{\eta_c} = (17.0 \pm 3.7 \pm 7.4)$  MeV.

The first observation of  $\chi_{cJ}$  ( $J=0,1,2$ ) decays to  $\Lambda\bar{\Lambda}$  is reported using  $\psi(2S)$  data collected with the BESII detector at the BEPC. The branching ratios are determined to be  $\mathcal{B}(\chi_{c0} \rightarrow \Lambda\bar{\Lambda}) = (4.7^{+1.3}_{-1.2} \pm 1.0) \times 10^{-4}$ ,  $\mathcal{B}(\chi_{c1} \rightarrow \Lambda\bar{\Lambda}) = (2.6^{+1.0}_{-0.9} \pm 0.6) \times 10^{-4}$  and  $\mathcal{B}(\chi_{c2} \rightarrow \Lambda\bar{\Lambda}) = (3.3^{+1.5}_{-1.3} \pm 0.7) \times 10^{-4}$ . Results are compared with model predictions.

### §1. Introduction

The Beijing Spectrometer (BES) is a general purpose solenoidal detector at the Beijing Electron Positron Collider (BEPC). BEPC operates in the center of mass energy range from 2 to 5 GeV with a luminosity at the  $J/\psi$  energy of approximately  $5 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ . BES (BESI) is described in detail in Ref. 1), and the upgraded BES detector (BESII) is described in Ref. 2). This paper presents some recent results; details can be found in the references.

### §2. Hadronic $\psi(2S)$ decays

Both  $J/\psi$  and  $\psi(2S)$  decays to light hadrons are expected to proceed dominantly via  $\psi \rightarrow ggg$ , with widths that are proportional to the square of the  $c\bar{c}$  wave function at the origin.<sup>3)</sup> This yields the expectation that

$$Q_X = \frac{B(\psi(2S) \rightarrow X_h)}{B(J/\psi \rightarrow X_h)} \approx \frac{B(\psi(2S) \rightarrow e^+e^-)}{B(J/\psi \rightarrow e^+e^-)} \approx 12\%$$

It was first observed by MarkII<sup>4)</sup> that the vector-pseudoscalar  $\rho\pi$  and  $K^*\bar{K}$  channels are suppressed with respect to the 12% expectation - the “ $\rho\pi$  puzzle”. BES finds a  $\rho\pi$  suppression factor of  $\sim 60$ ; this and many other BES  $\psi(2S)$  branching ratio results can be found in Refs. 5)-9).

Here, we report measurements of branching fractions for  $\psi(2S)$  decays involving an  $\omega$  or a  $\phi$ , including  $\omega\pi^+\pi^-$ ,  $b_1\pi$ ,  $\omega f_2(1270)$ ,  $\omega K^+K^-$ ,  $\omega p\bar{p}$ ,  $\phi\pi^+\pi^-$ ,  $\phi f_0(980)$ ,  $\phi K^+K^-$ , and  $\phi p\bar{p}$  final states, based on a data sample of  $(4.02 \pm 0.22) \times 10^6$   $\psi(2S)$  events collected with the BESI detector at the Beijing Electron-Positron Collider. Events are selected using particle identification and kinematic fitting. As an example, the  $K^+K^-$  invariant mass distribution for candidate  $\psi(2S) \rightarrow \phi\pi^+\pi^-$  events is shown in Fig. 1, where a clear  $\phi$  peak can be seen. In Fig. 2, the  $\pi^+\pi^-\pi^0$  mass distribution for  $\psi(2S) \rightarrow \omega K^+K^-$  events is shown; there is a clear  $\omega$  peak. We obtain the branching ratios and  $Q_X$  values shown in Table I. The branching fractions for  $b_1\pi$  and  $\omega f_2(1270)$  update previous BES results, while those for other decay modes are first measurements. The ratios of  $\psi(2S)$  and  $J/\psi$  branching fractions are smaller than the expected 12% rule by a factor of six for  $\omega f_2(1270)$ , by a factor of two for  $\omega\pi^+\pi^-$ ,  $\omega p\bar{p}$ , and  $\phi K^+K^-$ , while for other studied channels the ratios are consistent with expectations within errors. For more detail on this analysis, see Ref. 11).

Channel X	$B_{\psi(2S) \rightarrow X} (10^{-4})$	$Q_X (\%)$
$\omega\pi^+\pi^-$	$4.8 \pm 0.6 \pm 0.7$	$6.7 \pm 1.7$
$b_1^\pm\pi^\mp$	$3.2 \pm 0.6 \pm 0.5$	$11 \pm 3$
$\omega f_2(1270)$	$1.1 \pm 0.5 \pm 0.2$	$2.4 \pm 1.3$
		$< 1.5$
$\omega K^+K^-$	$1.5 \pm 0.3 \pm 0.2$	$20 \pm 8$
$\omega p\bar{p}$	$0.8 \pm 0.3 \pm 0.1$	$6.0 \pm 2.8$
$\phi\pi^+\pi^-$	$1.5 \pm 0.2 \pm 0.2$	$18 \pm 5$
$\phi f_0(980)$		
$\times (f_0 \rightarrow \pi^+\pi^-)$	$0.6 \pm 0.2 \pm 0.1$	
$\phi f_0(980)$	$1.1 \pm 0.4 \pm 0.1$	$33 \pm 15$
$\phi K^+K^-$	$0.6 \pm 0.2 \pm 0.1$	$7.3 \pm 2.6$
$\phi p\bar{p}$	$< 0.26$	$< 58$

Table I. Branching fractions of  $\psi(2S)$  and  $Q_X$  values for  $\psi(2S)$  and  $J/\psi$  hadronic decays. The  $B_{J/\psi}$  are taken from the PDG.<sup>10)</sup> To determine  $B(\phi f_0(980))$ , we use  $B_{f_0 \rightarrow \pi^+\pi^-} = 0.521 \pm 0.016$  (PDG'96).

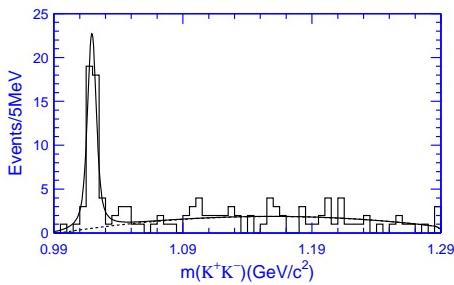


Fig. 1. The  $K^+K^-$  invariant mass distribution for candidate  $\psi(2S) \rightarrow \phi\pi^+\pi^-$  events.

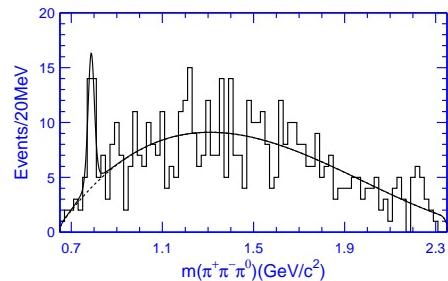


Fig. 2. The  $\pi^+\pi^-\pi^0$  mass distribution for candidate  $\psi(2S) \rightarrow \omega K^+K^-$  events.

In perturbative QCD, the radiative  $J/\psi$  and  $\psi(2S)$  decays should be similar to hadronic decays except instead of decaying into three gluons, the radiative mode

decays via two gluons and one photon. Thus one power of the coefficient  $\alpha_S$  is replaced by  $\alpha_{QED}$  in the cross section formula, and it is expected that the “12%” rule should also work for radiative decay modes<sup>12)</sup>. Hence the ratio of  $B(\psi(2S) \rightarrow \gamma X)$  to  $B(J/\psi \rightarrow \gamma X)$  for different final states  $X$  should be roughly 12%.

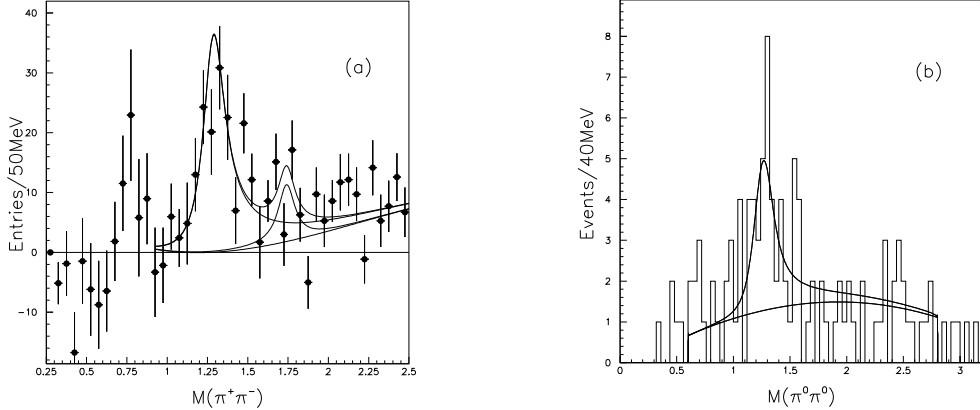


Fig. 3. (a):  $M_{\pi^+\pi^-}$  fit result. The four curves presented in the figure are the following: a background curve, a Breit-Wigner function to describe the  $f_2(1270)$  on top of the background, a Breit-Wigner function to describe the  $f_0(1710)$  on top of the background, and the total of the two Breit-Wigners and the background. The fitting range is 0.9 GeV to 2.5 GeV, since there is some  $\rho$  background below 0.9 GeV. The background at higher mass is due to processes such as  $\psi(2S) \rightarrow$  neutrals  $J/\psi$ ,  $J/\psi \rightarrow \pi^+\pi^-\pi^0$ . (b):  $M_{\pi^0\pi^0}$  fit result. The curves shown are a Breit-Wigner to describe the  $f_2(1270)$  and a polynomial to describe the background.

Here we report measurements of branching fractions for  $\psi(2S) \rightarrow \gamma\pi^+\pi^-$ ,  $\gamma\pi^0\pi^0$ ,  $\gamma K^+K^-$ ,  $\gamma K_S^0 K_S^0$ , and  $\gamma\eta\eta$ . The  $\pi\pi$  invariant mass distributions for  $\psi(2S) \rightarrow \gamma\pi\pi$  are shown in Fig. 3, where a clear  $f_2(1270)$  is seen. Results are summarized in Tables II through IV. First measurements of the  $\psi(2S) \rightarrow \gamma f_2(1270)$  and  $\psi(2S) \rightarrow \gamma f_0(1710) \rightarrow \gamma K^+K^-$  and  $\gamma K_S^0 K_S^0$  branching fractions are given. A clear  $f_0(1710)$  signal in  $\psi(2S)$  radiative decay into  $K^+K^-$  final states is observed. The results are consistent with the “12%” rule. In addition, first measurements of the branching fractions of  $\chi_{c0}$  and  $\chi_{c2}$  decay into  $\pi^0\pi^0$ ,  $\chi_{c0}$  decay into  $\eta\eta$ , and an upper limit of the branching fraction of  $\chi_{c2}$  decay into  $\eta\eta$  are reported (see Table IV). For more detail, see Ref. 13).

Final state	$B(\psi(2S) \rightarrow) (\times 10^{-4})$	$B(\psi(2S))/B(J/\psi)$
$\gamma f_2(1270)$	$2.12 \pm 0.19 \pm 0.32$	$(15.4 \pm 3.1)\%$
$\gamma f_0(1710) \rightarrow \gamma K^+K^-$	$0.302 \pm 0.045 \pm 0.066$	$(7.1^{+2.1}_{-2.0})\%$

Table II. Values for  $B(\psi(2S) \rightarrow) \gamma f_2(1270)$  and  $B(\psi(2S) \rightarrow) K^+K^-$  and comparison with the 12% rule.

Mode	$B(\times 10^{-4})$
$\psi(2S) \rightarrow \gamma f_2(1270)$ from $\gamma\pi^+\pi^-$	$2.08 \pm 0.19 \pm 0.33$
$\psi(2S) \rightarrow \gamma f_2(1270)$ from $\gamma\pi^0\pi^0$	$2.90 \pm 1.08 \pm 1.07$
$\psi(2S) \rightarrow \gamma f_2(1270)$ from $\gamma\pi\pi$	$2.12 \pm 0.19 \pm 0.32$
$\psi(2S) \rightarrow \gamma f_0(1710) \rightarrow \gamma\pi\pi$ from $\gamma\pi^+\pi^-$	$0.301 \pm 0.041 \pm 0.124$
$\psi(2S) \rightarrow \gamma f_0(1710) \rightarrow \gamma K^+K^-$	$0.302 \pm 0.045 \pm 0.066$
$\psi(2S) \rightarrow \gamma f_0(1710) \rightarrow \gamma K_S^0 K_S^0$	$0.206 \pm 0.094 \pm 0.108$

Table III. Branching fractions for  $\psi(2S) \rightarrow \gamma X \rightarrow \gamma P\bar{P}$  modes ( $P$  stands for pseudo-scalar).

Mode	$B(\times 10^{-3})$	$B \times B(\psi(2S) \rightarrow \gamma\chi_{c0,2}) (\times 10^{-4})$
$\chi_{c0} \rightarrow \pi^0\pi^0$	$2.79 \pm 0.32 \pm 0.57$	$2.42 \pm 0.28 \pm 0.44$
$\chi_{c2} \rightarrow \pi^0\pi^0$	$0.98 \pm 0.27 \pm 0.56$	$0.67 \pm 0.19 \pm 0.38$
$\chi_{c0} \rightarrow \eta\eta$	$2.02 \pm 0.84 \pm 0.59$	$1.76 \pm 0.73 \pm 0.49$
$\chi_{c2} \rightarrow \eta\eta$	$< 1.37$	$< 0.93$

Table IV. The  $\chi_c$  decay branching fractions for  $\chi_{c0,2} \rightarrow \pi^0\pi^0$  or  $\eta\eta$ .

### §3. BES $\psi(2S)$ Scan Results

In 1999, after the  $R$ -scan,<sup>14)</sup> BES did a careful  $\psi(2S)$  scan. The purpose was to improve the accuracies of the  $\psi(2S)$  parameters: the total width ( $\Gamma_t$ ), and partial widths into hadrons ( $\Gamma_h$ ),  $\mu^+\mu^-$  ( $\Gamma_\mu$ ), and  $\pi^+\pi^-J/\psi$  ( $\Gamma_{\pi^+\pi^-J/\psi}$ ), and the corresponding branching fractions,  $B(h)$ ,  $B(\mu)$ , and  $B(\pi^+\pi^-J/\psi)$ .  $B(\pi^+\pi^-J/\psi)$  and  $B(\mu)$  are important because these decays are used to identify  $\psi(2S)$  in B decays ( $B \rightarrow \psi(2S)K_S^0$ ).

A total of 24 energy points between 3.67 and 3.71 GeV were scanned. The total integrated luminosity was 760 nb<sup>-1</sup>. We assume  $\Gamma_t = \Gamma_h + \Gamma_\mu + \Gamma_e + \Gamma_\tau$ , along with lepton universality:  $\Gamma_e = \Gamma_\mu = \Gamma_\tau / 0.38847$ . The cross sections versus scan point energy and fit curves are shown in Fig. 4, and the fit results are given in Table V. We obtain a first measurement of  $\Gamma_{\pi^+\pi^-J/\psi}$ , and  $B(h)$ ,  $B(\mu)$ , and  $B(\pi^+\pi^-J/\psi)$  have improved precision compared to the PDG values.<sup>10)</sup> The value for  $\Gamma_t$  agrees within errors with a previous BES value of  $(252 \pm 37)$  keV.<sup>15)</sup> A complete description of this work can be found in Ref. 16).

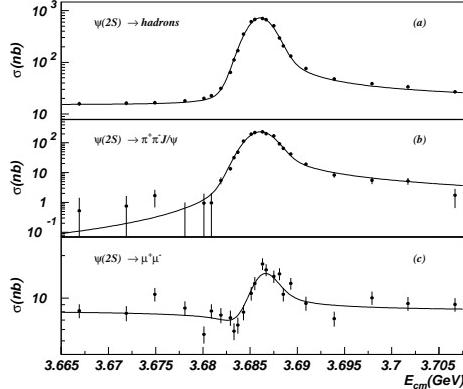


Fig. 4. The cross section for (a)  $e^+e^- \rightarrow$  hadrons, (b)  $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ , and (c)  $e^+e^- \rightarrow \mu^+\mu^-$  versus center-of-mass energy. The solid curves represent the results of the fit to the data.

#### §4. $\eta_c$ Parameters

Value	BES	PDG2002
$\Gamma_t$ (keV)	$264 \pm 27$	$300 \pm 25$
$\Gamma_h$ (keV)	$258 \pm 26$	
$\Gamma_{\pi\pi J/\psi}$ (keV)	$85.4 \pm 8.7$	
$\Gamma_\mu$ (keV)	$2.44 \pm 0.21$	
$\mathcal{B}_h$ (%)	$97.79 \pm 0.15$	$98.10 \pm 0.30$
$\mathcal{B}_{\pi\pi J/\psi}$ (%)	$32.3 \pm 1.4$	$30.5 \pm 1.6$
$\mathcal{B}_\mu$ (%)	$0.93 \pm 0.08$	$0.7 \pm 0.09$

Table V.  $\psi(2S)$  scan results and comparison with the PDG2002.<sup>10)</sup>  $\Gamma_\mu$  value given using the assumption  $\Gamma_e = \Gamma_\mu$ .

total width  $\Gamma_{\eta_c} = (11.0 \pm 8.1 \pm 4.1)$  MeV.<sup>18)</sup>

Here, the mass and width have been determined using our BESII 58 M  $J/\psi$  event sample. We use the channels  $J/\psi \rightarrow \gamma\eta_c$ , with  $\eta_c \rightarrow p\bar{p}$ ,  $K^+K^-\pi^+\pi^-$ ,  $\pi^+\pi^-\pi^+\pi^-$ ,  $K^\pm K_S^0\pi^\mp$ , and  $\phi\phi$ . Events are selected using particle identification and kinematic fitting. Figs. 5 and 6 show the mass distributions in the  $\eta_c$  mass region for  $J/\psi \rightarrow \gamma\eta_c$ ,  $\eta_c \rightarrow p\bar{p}$  and  $\eta_c \rightarrow K^+K^-\pi^+\pi^-$ , respectively. Combining the five decay channels, we obtain  $M_{\eta_c} = (2977.5 \pm 1.0 \pm 1.2)$  MeV and  $\Gamma_{\eta_c} = (17.0 \pm 3.7 \pm 7.4)$  MeV, to be compared to the current PDG values:  $M_{\eta_c} = (2979.7 \pm 1.5)$  MeV and  $\Gamma_{\eta_c} = (16.0^{+3.6}_{-3.2})$  MeV.<sup>10)</sup> The results for the mass and width are compared with previous measurements, including previous BES measurements, in Figs. 7 and 8. The results are in good agreement with previous BES measurements and the PDG fit values. More detail on this analysis can be found in Ref. 19).

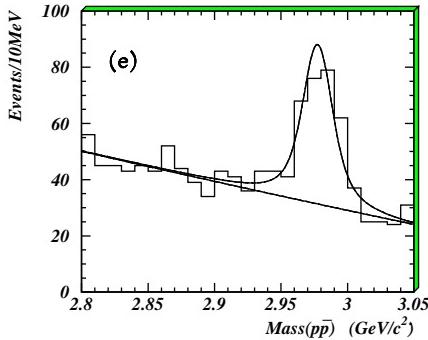


Fig. 5. The  $m_{p\bar{p}}$  invariant mass distribution in the  $\eta_c$  region.

The mass and width of the  $\eta_c$  are rather poorly known; the confidence level for the PDG weighted average mass is only 0.001.<sup>10)</sup> Previously BES measured the  $\eta_c$  mass using the BESI 4.02 M  $\psi(2S)$  sample and obtained  $M_{\eta_c} = (2975.8 \pm 3.9 \pm 1.2)$  MeV.<sup>17)</sup> BES also used 7.8 M BESI  $J/\psi$  events and obtained  $M_{\eta_c} = (2976.6 \pm 2.9 \pm 1.3)$  MeV.<sup>18)</sup> For the two data sets combined,  $M_{\eta_c} = (2976.3 \pm 2.3 \pm 1.2)$  MeV and the to-

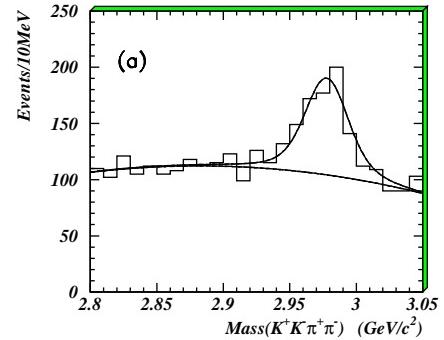
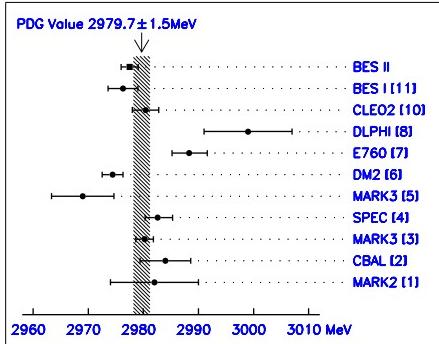
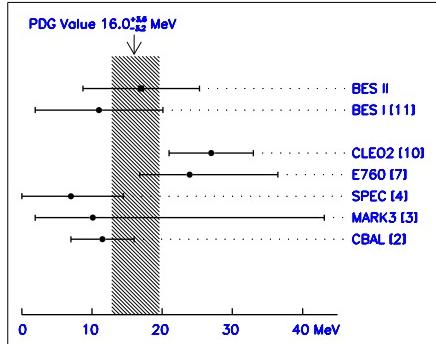


Fig. 6. The  $m_{K^+K^-\pi^+\pi^-}$  invariant mass distribution in the  $\eta_c$  region.

#### §5. $\chi_J \rightarrow \Lambda\bar{\Lambda}$

It has been shown both in theoretical calculations and experimental measurements that the lowest Fock state expansion (color singlet mechanism, CSM) of char-

Fig. 7. Mass measurements of the  $\eta_c$  meson.Fig. 8. Width measurements of the  $\eta_c$  meson.

monium states is insufficient to describe P-wave quarkonium decays. Instead, the next higher Fock state (color octet mechanism, COM) plays an important role.<sup>20), 21)</sup> Our earlier measurement<sup>21)</sup> of the total width of the  $\chi_{c0}$  agrees rather well with the COM expectation. The calculation of the partial width of  $\chi_{cJ} \rightarrow p\bar{p}$ , by taking into account the COM of  $\chi_{cJ}$  decays and using a carefully constructed nucleon wave function,<sup>22)</sup> obtains results in reasonable agreement with measurements.<sup>10)</sup> The nucleon wave function was then generalized to other baryons, and the partial widths of many other baryon anti-baryon pairs predicted. Among these predictions, the partial width of  $\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}$  is about half of that of  $\chi_{cJ} \rightarrow p\bar{p}$  ( $J=1,2$ ).<sup>22)</sup>

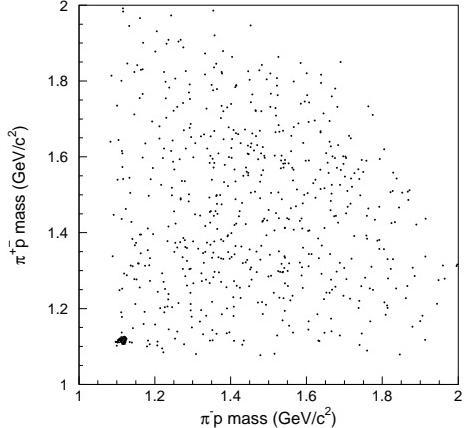
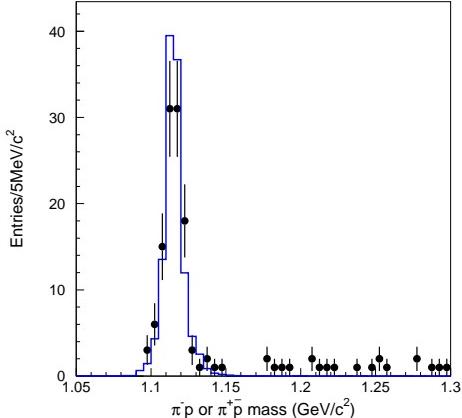
Fig. 9. Scatter plot of  $\pi^+\bar{p}$  versus  $\pi^-p$  invariant mass for selected  $\gamma\pi^+\pi^-\bar{p}\bar{p}$  events with the  $\pi^+\pi^-\bar{p}\bar{p}$  mass in the  $\chi_{cJ}$  mass region.Fig. 10. Mass distribution of  $\pi^+\bar{p}$  ( $\pi^-p$ ) recoiling against a  $\Lambda$  ( $\bar{\Lambda}$ ) (mass < 1.15 GeV) for events in the  $\chi_{cJ}$  mass region. Dots with error bars are data and the histogram is the Monte Carlo simulation, normalized to the  $\Lambda$  signal region (two entries per event).

Fig. 9 shows a scatter plot of the  $\pi^+\bar{p}$  versus the  $\pi^-p$  invariant mass for events with  $\pi^+\pi^-\bar{p}\bar{p}$  mass between 3.38  $\text{GeV}/c^2$  and 3.60  $\text{GeV}/c^2$ , using the BESII 15 million  $\psi(2S)$  event sample. The cluster of events in the lower left corner shows a

clear  $\Lambda\bar{\Lambda}$  signal. Selecting events in  $\chi_{cJ}$  mass region and requiring the mass of  $\pi^+\bar{p}$  ( $\pi^-p$ ) to be smaller than  $1.15 \text{ GeV}/c^2$ , the  $\pi^-p$  ( $\pi^+\bar{p}$ ) mass distribution shown in Fig. 10 is obtained. A clear  $\Lambda$  signal can be seen, and the background below the peak is very small.

After requiring that both the  $\pi^+\bar{p}$  and the  $\pi^-p$  mass lie within twice the mass resolution around the nominal  $\Lambda$  mass, the  $\Lambda\bar{\Lambda}$  invariant mass distribution shown in Fig. 11 is obtained. There are clear  $\chi_{c0}$ ,  $\chi_{c1}$ , and  $\chi_{c2} \rightarrow \Lambda\bar{\Lambda}$  signals. The highest peak around the  $\psi(2S)$  mass is due to  $\psi(2S) \rightarrow \Lambda\bar{\Lambda}$  with a fake photon.

Background from non  $\Lambda\bar{\Lambda}$  events is estimated from the  $\Lambda$  mass sidebands, and this can be described in fitting the  $\Lambda\bar{\Lambda}$  mass spectrum by a linear background. The background from channels with  $\Lambda\bar{\Lambda}$  production, including  $\psi(2S) \rightarrow \Lambda\bar{\Lambda}$ ,  $\psi(2S) \rightarrow \Sigma^0\bar{\Sigma}^0$ ,  $\psi(2S) \rightarrow \Lambda\bar{\Sigma}^0 + c.c.$ ,  $\psi(2S) \rightarrow \Xi^0\bar{\Sigma}^0 + c.c.$ ,  $\psi(2S) \rightarrow \gamma\chi_{cJ}$ ,  $\chi_{cJ} \rightarrow \Sigma^0\bar{\Sigma}^0 \rightarrow \gamma\gamma\Lambda\bar{\Lambda}$ , and  $\psi(2S) \rightarrow \pi^+\pi^- J/\psi \rightarrow \pi^+\pi^- p\bar{p}$ , are simulated by Monte Carlo.

Fixing the  $\chi_{c0}$ ,  $\chi_{c1}$  and  $\chi_{c2}$  mass resolutions at their Monte Carlo predicted values, and fixing the widths of the three  $\chi_{cJ}$  states to their world average values,<sup>10)</sup> the mass spectrum (Fig. 11) was fit with three Breit-Wigner functions folded with Gaussian resolutions and background, including a linear term representing the non  $\Lambda\bar{\Lambda}$  background and a component representing the  $\Lambda\bar{\Lambda}$  background. The unbinned maximum likelihood method was used to fit the events with  $\Lambda\bar{\Lambda}$  mass between  $3.22$  and  $3.64 \text{ GeV}/c^2$ , and a likelihood probability of  $27\%$  was obtained, indicating a reliable fit. Fig. 11 shows the fit result, and the fitted masses are  $(3425.6 \pm 6.3)\text{MeV}/c^2$ ,  $(3508.5 \pm 3.9) \text{ MeV}/c^2$  and  $(3560.3 \pm 4.6) \text{ MeV}/c^2$  for  $\chi_{c0}$ ,  $\chi_{c1}$  and  $\chi_{c2}$ , respectively, in agreement with the world average values.<sup>10)</sup> The branching ratios of  $\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}$  obtained are

$$\begin{aligned}\mathcal{B}(\chi_{c0} \rightarrow \Lambda\bar{\Lambda}) &= (4.7^{+1.3}_{-1.2} \pm 1.0) \times 10^{-4}, \\ \mathcal{B}(\chi_{c1} \rightarrow \Lambda\bar{\Lambda}) &= (2.6^{+1.0}_{-0.9} \pm 0.6) \times 10^{-4}, \\ \mathcal{B}(\chi_{c2} \rightarrow \Lambda\bar{\Lambda}) &= (3.3^{+1.5}_{-1.3} \pm 0.7) \times 10^{-4},\end{aligned}$$

where the first errors are statistical and the second are systematic.

Compared with the corresponding branching ratios of  $\chi_{cJ} \rightarrow p\bar{p}$ ,<sup>10)</sup> the branching ratios of  $\chi_{c1}$  and  $\chi_{c2} \rightarrow \Lambda\bar{\Lambda}$  agree with the corresponding branching ratios to  $p\bar{p}$  within two sigma. This is somewhat in contradiction with the expectations from Ref. 22), although the errors are large.

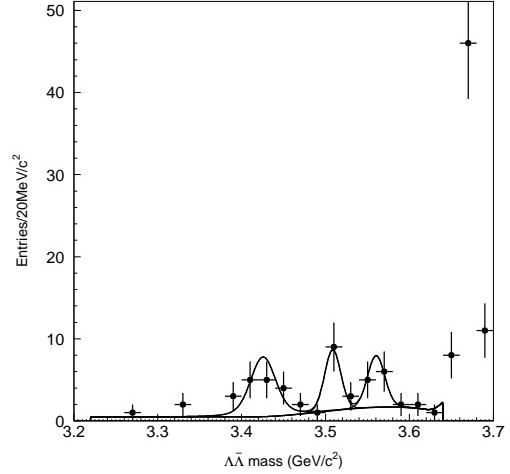


Fig. 11. Mass distribution of  $\gamma\Lambda\bar{\Lambda}$  candidates fitted with three resolution smeared Breit-Wigner functions and background, as described in the text.

As for  $\chi_{c0} \rightarrow \Lambda\bar{\Lambda}$ , the measured value agrees with the  $p\bar{p}$  measurements from BES and E835<sup>21), 23)</sup> within 2 standard deviations. One should also note that there is no prediction for  $\mathcal{B}(\chi_{c0} \rightarrow \Lambda\bar{\Lambda})$ . More detail may be found in Ref. 24).

## §6. Summary

Branching fractions are determined, many for the first time, using the 4.2 million BESI  $\psi(2S)$  event sample. They are used to test the “12 %” rule. Results from a fit to a careful scan in the vicinity of the  $\psi(2S)$  are presented. The 58 million BESII  $J/\psi$  event sample is used to measure the mass and width of the  $\eta_c$ . Finally,  $\Lambda\bar{\Lambda}$  events are observed for the first time in  $\chi_{cJ}$  decays using the BESII 15 million  $\psi(2S)$  event sample, and corresponding branching ratios are determined.

## Acknowledgements

The author would like to thank Prof. S. Ishida, Prof. K. Takamatsu, and all the other members of the Sigma Group for their support during the Symposium.

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